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Abstract Acute abdominal pain is one of the most common causes for referrals to the emergency department. The sudden onset of severe abdominal pain characterising the "acute abdomen" requires rapid and accurate identification of a potentially life-threatening abdominal pathology to provide a timely referral to the appropriate physician. While the physical examination and laboratory investigations are often non-specific, computed tomography (CT) has evolved as the first-line imaging modality in patients with an acute abdomen. Because the new multi-detector CT (MDCT) scanner generations provide increased speed, greater volume coverage and thinner slices, the acceptance of CT for abdominal imaging has increased rapidly. The goal of this article is to discuss the role of MDCT in the diagnostic work-up of acute abdominal pain.

Keywords Computed tomography · Abdomen · Diseases

Introduction

The term "acute abdomen" defines a clinical syndrome characterised by the sudden onset of severe abdominal pain requiring emergency medical or surgical treatment [1].

In an analysis of more than 10,000 patients presenting with acute abdominal pain the aetiology could not be determined in one-third of these cases [2]. Of those patients in whom a diagnosis was made, 28% had appendicitis, 9.7% acute cholecystitis, 4.1% small bowel obstruction, 4% acute gynaecological disease, 2.9% acute pancreatitis, 2.9% acute renal colic, 2.5% perforated peptic ulcer, and 1.5% acute diverticulitis [2]. Various potentially life-threatening processes can cause acute abdominal pain, thus a rapid and accurate diagnosis is essential to reduce morbidity and mortality. Physical and laboratory examinations are often non-specific, and the clinical presentation of many entities overlaps. Therefore, diagnostic and efficient imaging evaluations are indispensable. Computed tomography (CT) has gained widespread acceptance as the first-line imaging modality in patients presenting with acute abdominal pain [3–5]. It is the most time-effective and accurate imaging technique, and, if the working clinical diagnosis is incorrect, CT provides sufficient information for an alternative diagnosis. The introduction of multi-detector CT (MDCT) has yielded additional advantages, which enhance the role of CT in patients with acute abdominal pain [4, 6, 7].

In this review, we discuss the diagnostic potential of MDCT and its role in common causes of acute abdominal pain.

MDCT techniques

Advantages of MDCT

The evolution from single-slice CT to current MDCT scanners has resulted in several important advantages. First, the shortened acquisition time increases scanner productivity and reduces motion artefacts by scanning the entire abdomen in a single breath-hold, which is essential in acutely ill patients [6]. Second, thin collimation enables sub-millimetre isotropic imaging, permitting reconstructions in any arbitrary plane with a spatial resolution similar to that of the axial plane. Third, better contrast bolus exploitation allows precise separation of multiple phases of enhancement, which is especially useful in the evaluation of vascular diseases. Furthermore, increased computing speed of state-of-the-art workstations has shortened reconstruction times, facilitating faster radiological interpretation.

Post-processing techniques and reporting

Three main post-processing techniques are used. Multiplanar reconstructions (MPRs) are useful for interpretation of abdominal diseases as they allow the scanned volume to be viewed in any arbitrary plane interactively determined by the viewer. These reconstructions are especially useful when tubular structures, such as vessels, ureters, and bowel, are followed. Maximum intensity projections (MIPs) are obtained by the projection onto an image plane of the highest attenuation voxels encountered through a volume, which allows for evaluation of structures that are not lying in a single plane. MIP is useful for CT angiography and CT urography [8]. Main disadvantages are that vessels adjacent to bones may be obscured. The reconstruction of volume-rendered (VR) images is particularly helpful for visualisation of complex anatomy and pathology of visceral vasculature and best delineates a tortuous course of vessels and small branches compared with MPR or axial images alone [9].

The evaluation of abdominal CT studies is routinely performed on dedicated workstations by interactive viewing. The following algorithmic approach is helpful in most patients:

Initial viewing of the axial source images in scroll-through mode is mandatory.

Interactive viewing in the coronal plane is usually done in all patients, and in the majority of cases axial and coronal images are sufficient for evaluating abdominal disease.

Additional sagittal, oblique, or curved planar reconstructions may facilitate diagnosis in equivocal findings.

In suspected vascular or ureteral disease, MIPs are usually reconstructed in dedicated planes and slab-thickness is adapted to include the area of interest.

In suspected vascular pathology, VR images may be helpful in understanding complex vascular pathology and reporting the results to clinical colleagues.

Finally, all pathological conditions should be verified again on the axial images to avoid false positive findings, because all post-processing techniques have the potential hazard of loss of valuable information when improperly used.

The major disadvantage of MDCT examinations is the large number of data and images that are produced [10], making efficient and accurate reporting on hard-copy images difficult [11]. In addition, it is obviously not cost-effective to hard-copy all images [6]. For reporting, axial slices with a thickness of 5 mm and an increment of 10 mm are printed on hard copies. In ureteral stone disease, reporting on hard copies may be limited to coronal reformations and coronal MIPs. Additional MPR, MIP, and VR reconstructions are not essential for the reporting of every examination and should be limited in the further evaluation of an area of abnormality, particularly when axial images alone make interpretation difficult [12].

Examination protocols

At our institution, patients presenting with acute abdominal pain in the emergency department are scanned on a 16-row MDCT scanner (Sensation 16, Siemens, Forchheim, Germany) using the following parameters: tube voltage 120 kV, tube current 225 mAs, slice collimation 16 mm×0.75 mm, pitch 1.0. Routinely, slices with a thickness of 2.0 mm (increment 1.0 mm) and a medium soft-tissue reconstruction kernel (B30f) are used for evaluation. Based on the working clinical diagnosis, optimising the acquisition parameters is essential to maximise diagnostic accuracy [13]. For instance, narrow collimation (1 mm slice thickness, 0.5 mm increment) is used for CT angiography.

Application of contrast agent

As recently reviewed, different strategies for the application of contrast agent (oral/rectal/intravenous) are used, depending on the working clinical diagnosis [3]. Scanning without the application of contrast agent is the fastest, but most limited, strategy. However, Malone [14] has used this strategy very effectivly in patients with acute abdominal pain. Depending on the working clinical diagnosis, optimisation of the contrast administration protocol is recommended (Table 1). However, the application of oral, rectal and intravenous contrast is beneficial in most patients because of the often equivocal clinical presentation. When intravenous administration of contrast agent is indicated, adapted to the body weight, 120 ml to 150 ml of iodinated contrast material (270 mg iodine/ml), injected at a rate of 3 ml/s, is adequate. If such administration has been indicated, scanning for arterial phase imaging should be initiated 20–30 s after the start of injection. Otherwise, scanning should begin after a delay of 85 s for portal venous phase imaging. Delayed images, acquired 8 min after injection, are helpful in cases of suspected pyelonephritis or when opacification of the bladder may be desired. No intravenously injected contrast agent is administered in

Table 1 Common causes of acute abdominal pain: recommended CT contrast agent application and typical findings

Location of acute pain/working clinical diagnosis	Contrast material			Typical CT findings	Comments
	Oral	i.v.	Rectal		
Right upper quadrant					
Acute cholecystitis	−	+	−	Gall bladder wall thickening >3 mm, distended gall bladder lumen, pericholecystic fluid or haziness, increased attenuation gall bladder bile, subserosal oedema	CT is superior to sonography in depicting complications
Right lower quadrant					
Appendicitis	+	+	+	Fluid-filled and enlarged appendix, focal caecal apical thickening, peri-appendiceal fat stranding, calcified appendicoliths, appendiceal wall enhancement	CT is highly accurate when a combination of CT signs is used. i.v., oral, and rectal administration of contrast agent is recommended. i.v. administration of contrast medium is especially useful in patients with less intra-abdominal fat
Left lower quadrant					
Diverticulitis	−	+	+	Presence of diverticula, inflammatory change in the peri-colic fat, mural thickening, air bubbles, free fluid collection	Absence of fat stranding and mural thickening essentially exclude diverticulitis
Diffuse abdominal pain					
Gastro-enterocolitis	+	+	+	Mural thickening, peri-colic inflammatory changes, halo/target sign, accordion sign	CT is recommended in only atypical clinical presentation
Small bowel obstruction	(+)	+	−	Transition zone from distended to decompressed bowel; C-shaped, U-shaped, "coffee bean" configuration of the bowel loop and "whirlpool-sign" in strangulated bowel	CT is useful in differentiating between benign and malignant obstruction, strangulated and closed-loop obstruction, and mechanical obstruction and paralytic ileus. Contrast agent is not routinely administered orally because fluid-filled loops provide "natural contrast"
Ischaemic bowel disease	−	+	−	Bowel dilatation, wall thickening, abnormal bowel wall enhancement, target sign, intestinal pneumatosis, ascites	Acquisition of arterial and portal venous phase, thin-collimated reconstructions, and MIP/VRT of the vessels are recommended
GI tract perforation	+	+	+	Extra-luminal air and fluid, contrast extravasation, occasionally local inflammatory changes	Additional "lung window" setting is recommended. Location of air does not necessarily correlate with site of perforation
Flank/epigastric pain					
Urolithiasis	−	−	−	Radio-opaque calculi, peri-ureteral stranding, hydro-ureter, hydronephrosis	Nearly 100% of all calculi are detected using thin collimations. Use of coronal reconstructions are more effective. Oral, i.v., or rectal administration of contrast agent may be required for alternative diagnoses
Acute pancreatitis	(+)	+	−	Enlarged gland, intrapancreatic and peri-pancreatic fluid collections; in necrotising pancreatitis unenhanced sharply demarcated regions	As orally administered contrast medium use water only. Arterial and portal venous phase imaging in thin-slice collimation is recommended. Findings on CT correlate well with severity of disease

i.v. intravenous, − unenhanced, + enhanced, *VRT* volume-rendering technique suspected ureteral stone or renal insufficiency. CT angiography is useful in patients with suspected haemorrhage and bowel ischaemia with arterial or venous occlusion. Then, 120 ml of higher concentration contrast material (above 300 mg iodine/ml), at an injection rate of 3–4 ml/s, is mandatory. Use of oral contrast material is recommended, in most cases, if severity of symptoms allows for the delaying of imaging for at least 1 h. Oral administration of contrast material (800–1,000 ml water-soluble contrast agent containing 2% iodine) is indicated in most patients, with the exception of suspected high-grade bowel obstruction, ureteral stone, acute haemorrhage, or acute pancreatitis. Oral administration causes some delay in diagnosis, because most patients require at least 1 h transit time for adequate bowel opacification. The combination of orally and intravenously administered enhancement agents may help one to distinguish between common intestinal diseases by depicting variations in bowel wall attenuation [15]. When rectal administration of contrast material is indicated, 100 ml water-soluble contrast agent (containing 2% iodine) is instilled via a rectal enema.

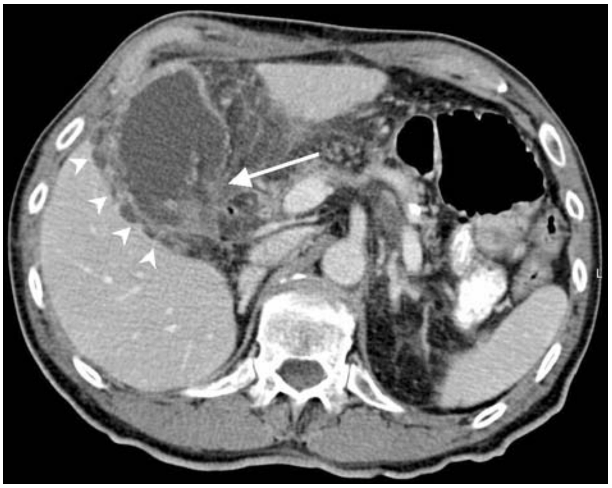

Fig. 1 Perforated acute calculous cholecystitis, in a 67-year-old man with acute abdominal pain in the RUQ. MDCT demonstrates an enlarged gall bladder with mural thickening and discontinuity of the medial wall indicative of perforation (*arrow*). In addition, multiple peri-cholecystic abscesses (*arrowheads*) and inflammatory changes in the peri-cholecystic fat are present

Role of MDCT in common causes of acute abdominal pain

For didactic reasons, the common causes of acute abdominal pain are classified by their topographic location in abdominal quadrant, diffuse, and flank or epigastric pain.

Right upper quadrant pain

The most common cause of acute abdominal pain in the right upper quadrant (RUQ) is acute cholecystitis, especially in the elderly patient [2]. Although sonography is the preferred imaging method, patients with acute RUQ pain often undergo CT as initial examination. CT may than be useful in diagnosing acute, complicated, calculous or acalculous cholecystitis when the diagnosis is difficult to establish by sonography. If CT is the initial imaging modality performed in a patient with abdominal pain, recognition of typical CT findings may eliminate the need for any additional imaging modality, thus facilitating appropriate and expedient management. For most patients, a standard CT protocol with intravenous administration of contrast agent and portal venous phase imaging is adequate.

The most sensitive CT findings in acute cholecystitis are mural thickening of more than 3 mm with increased attenuation in the setting of a distended gall bladder [16]. Other findings include peri-cholecystic fluid or haziness, increased attenuation of the gall bladder bile, and subserosal oedema [16] (Fig. 1). Transient, focal, increased attenuation of the liver parenchyma can develop adjacent to the inflamed gall bladder, indicating hepatic arterial hyperaemia and early venous drainage [17]. A combination of these CT findings has a sensitivity comparable to that of sonography in detecting acute cholecystitis [13].

Dislocation of gallstones in the biliary duct may lead to biliary colic. Patients then often present with recurrent episodes of RUQ pain, fever, and jaundice. The most reliable CT finding is the depiction of the stone within the bilary duct (Fig. 2). MDCT facilitates narrow collimation and multiplanar reconstructions, which may help to detect small calculi in the biliary system [6, 13], and visualisation of low- and high-attenuated rings allows for identification of mixed cholesterol–calcium stones, often resulting in distal common bile duct obstruction [13]. In the absence of acute pancreatitis or another detectable cause of distal common bile duct obstruction, dislocated gallstone, biliary stricture, and small ampullary mass should be taken into consideration in the differential diagnosis.

Common alternative diagnoses of acute RUQ pain include omental infarction, retrocaecal appendicitis, right-sided diverticulitis, perforated duodenal ulcer, and, rarely, amoebic liver abscess or spontaneous rupture of a hepatic neoplasm.

Left upper quadrant pain

Conditions causing localised pain in the left upper quadrant (LUQ) are rare, with splenic infarction, splenic abscess, sickle cell crisis, and gastric ulcer being the most frequent. In addition, patients with acute pancreatitis can present with LUQ pain.

Common causes of splenic infarction include bacterial endocarditis, portal hypertension, and underlying splenomegaly [13]. On CT, focal infarcts appear as hypodense

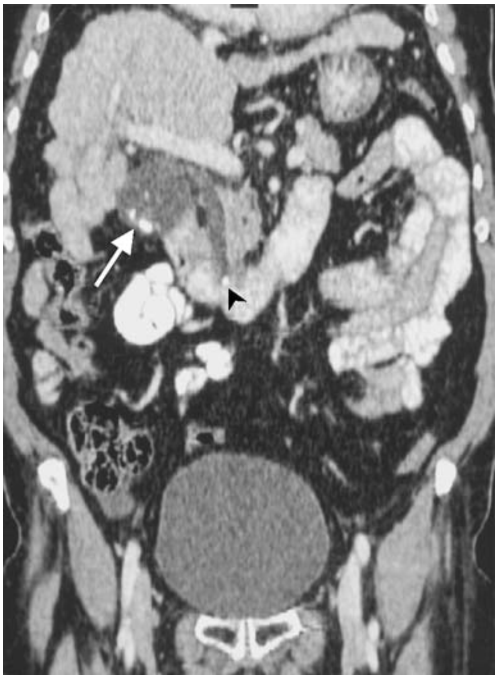

Fig. 2 Biliary obstruction in gallstone disease in a 52-year-old man with acute abdominal pain in the RUQ and liver cirrhosis. Coronal MDCT reconstruction shows multiple calcified stones in the gall bladder (*arrow*) and proximal biliary dilatation secondary to a small obstructing calcified stone in the distal common bile duct (*arrowhead*)

wedge-shaped areas extending to the splenic surface. Global infarction can result in diffuse hypodensity and can mimic splenic abscess or tumour [18]. For evaluation of splenic pathologies, intravenous administration of contrast medium in an arterial and portal venous phase are recommended. MDCT can improve depiction of surrounding splenic vasculature and associated pancreatic changes by thinner collimation and the use of cine-display.

Right lower quadrant pain

The most common cause of acute abdominal pain is appendicitis. Although the preoperative diagnosis can be established on the basis of clinical findings, the symptoms of appendicitis may be atypical and mimic other gastrointestinal or genitourinary conditions. Ultrasound is the first-line imaging modality in children and in women of reproductive age, because radiation exposure should be avoided and the small body sizes usually allow for high-quality sonograms. In young women, many causes of right lower quadrant (RLQ) pain are related to gynaecological causes and have to be excluded initially. However, CT is more sensitive than ultrasound in patients with equivocal presentation [19]. The judicious use of CT in patients with equivocal clinical findings has resulted in a negative appendicectomy rate of 2.5–7% [19, 20]. In MDCT, multiplanar viewing provides improved appendiceal visualisation and enhances confidence as to the presence or absence of acute appendicitis [7] (Fig. 3). Coronal reformations are especially useful for visualising the appendix in an unusual location.

Visualisation of a fluid-filled enlarged appendix and focal caecal apical thickening are the most specific CT signs, while peri-appendiceal fat stranding is most sensitive but less specific [21]. Unfortunately, acute appendicitis could also appear without caecal apical thickening or peri-appendiceal fat stranding. Other helpful CT findings include calcified appendicoliths and appendiceal wall enhancement after intravenous administration of contrast agent. However, non-visualisation of the appendix indicates absence of acute appendicitis [22]. The appearance of the abnormal appendix will vary with the degree of inflammation present. Recently, new MDCT criteria of the normal appendix have been described [23]. The overall diameter of the normal appendix may vary between 5 mm and 11 mm and is larger than 6 mm in 70% [23]. An appendicolith may be seen in 13%. Despite MDCT, however, 18% of normal appendices were not detected [20]. Preoperative CT not only establishes the diagnosis and depicts unusual appendix location but also helps guide surgical planning. Appendicitis with peri-appendiceal fluid, inflammatory mass, or abscess are good in-

Fig. 3 Acute appendicitis and walled-off perforation in a 30-year-old man with fever, elevated white blood cell count, and acute abdominal pain in the RLQ. Coronal reconstructed MDCT depicts the dilated appendix in a retro-ileal position, with circumferential mural enhancement, peri-appendiceal fat stranding, and a small calcified appendicolith in the appendiceal apex (*arrowhead*). Because of extra-luminal gas (*arrow*) one can make the diagnosis of an acute appendicitis with complicating walled-off perforation. This case highlights the use of coronal MPR in identifying the appendix in uncommon anatomical locations

dicators for conversion of laparoscopic to open appendicectomy [24].

A number of different protocols for the application of contrast agents is used for evaluating acute appendicitis. Scans can be performed without contrast agent [25], with orally and intravenously administered contrast agent [26], with contrast agent applied by oral and colonic routes [27], and with colonically administered contrast medium only [21]. Orally and colonically administered contrast materials yield a high diagnostic accuracy as well as the identification of alternative diagnoses in 80% of cases [27].

The list of differential diagnoses of RLQ pain is long and includes acute typhlitis, Crohn's disease, caecal diverticulitis, Meckel's diverticulitis (Fig. 4), mesenteric adenitis, right-sided omental infarction, perforated caecal carcinoma, pelvic inflammatory disease, complications of ovarian cysts (torsion, rupture), ectopic pregnancy, or urolithiasis. Non-specific signs seen with appendicitis, such as fat stranding, adjacent bowel wall thickening, and free fluid collection, also occur in these conditions. The identification of a normal appendix is the key to excluding appendicitis [21].

Fig. 4 Meckel's diverticulitis in a 48-year-old man with acute abdominal pain in the RLQ. Coronal reconstructed MDCT with maximum-intensity projection demonstrates a dilated diverticulum (*arrowhead*) arising from the small bowel with wall enhancement and adjacent fat stranding, while the appendix, shown in the inlay (*curved arrow*), is normal. These findings are indicative of inflammation of a Meckel's diverticulum

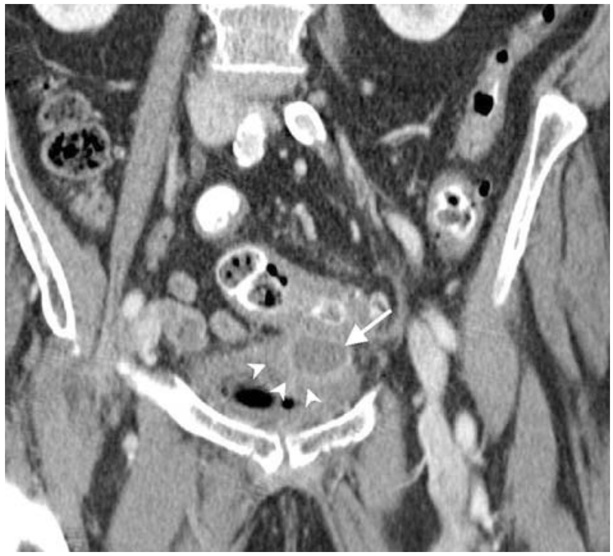

Fig. 5 Colovesical fistula in acute diverticulitis in a 74-year-old woman with acute abdominal pain in the left lower quadrant (LLQ) and known diverticular disease. Coronal reconstructed MDCT shows a peri-colonic abscess (*arrow*), adjacent focal bladder wall thickening (*arrowheads*) and air in the bladder, indicating a colovesical fistula in acute diverticulitis

Left lower quadrant pain

Diverticular disease is very common in patients older than 65 years, and up to 25% of those patients will develop sigmoid diverticulitis [28]. Clinical misdiagnosis rates range from 34% to 67% [29]. Conversely, MDCT is both sensitive and specific in making a diagnosis of diverticulitis [30]. The most common CT finding of diverticulitis, present in almost 98% of patients, is inflammatory change in the peri-colic fat [31]. Although fat stranding is unspecific, disproportionality, with stranding more severe than expected for the degree of bowel wall thickening, has recently been reported to belong to four main entities: diverticulitis, appendicitis, epiploic appendagitis and omental infarction [32]. Other findings include focal colonic wall thickening and free fluid collection. Absence of fat stranding and mural thickening essentially exclude diverticulitis. In advanced disease, peri-colonic inflammation can progress to phlegmon or abscess. CT is the imaging technique of choice for depicting complications, including walled-off perforation, intraperitoneal perforation, fistulae (Fig. 5) and bowel obstruction [30]. With MDCT, narrow collimation facilitates the estimation of stenosis or changes in thickness and contrast of bowel wall. Coronal reformations may provide improved differentiation between normal and abnormal bowel walls. The use of near-isotropic volumes results in reconstructions of imaging planes optimised to the bowel segment in question, or, when curved reconstructions are used, fistulae can be delineated in their entire course. Additional benefits of CT include the guidance of therapeutic intervention in complicated forms of diverticular disease [33] and the provision of an alternative diagnosis in patients without diverticulitis. CT-guided drainage of pericolic or pelvic abscesses can be safely and successfully performed in most patients [33]. However, even a successful drainage should serve as only a temporising measure until an elective surgical resection can be performed [33]. Alternative conditions that can clinically mimic sigmoid diverticulitis include colon obstruction secondary to sigmoid carcinoma, gynaecological diseases, or ureteral stone disease. Another alternative diagnosis is primary epiploic appendagitis. Patients with these conditions often lack associated fever or leukocytosis [34]. CT findings are often characteristic, presenting an oval-shaped fatty mass with an associated rim of high attenuation around the periphery of the inflamed appendage, peri-colonic fat streaking, and, occasionally, focal thickening of the adjacent colonic wall [34]. Similar CT findings may be present in segmental omental infarction, a condition typically located on the right side and related to obesity and recent surgery. Usage of MPRs for anatomical relation relative to the colon and disproportionality of fat standing may help in differentiating both entities [32].

While most investigators recommend the administration of contrast material only via a rectal enema, intravenous injection of contrast agent is helpful in the detection of peri-colonic inflammation, differentiation of peri-colic abscesses from adjacent bowel loops, and characterisation of pelvic fluid collection [13]. Consequently, if complications are suspected, CT examination should be performed with both colonic and intravenous administration of contrast medium.

Diffuse abdominal pain

Diffuse abdominal pain is due to irritation of the peritoneum or large portions of the gut and is most frequently caused by infectious or inflammatory bowel disease (IBD), bowel obstruction, acute mesenteric ischemia, and gastrointestinal tract perforation. With increasing use of MDCT in abdominal pain, gastritis and right-sided infectious colitis are diagnosed more often.

Infectious bowel disease

Gastro-enterocolitis is responsible for approximately 70% of patients with abdominal pain admitted to the emergency department [35]. The vast majority does not require imaging. However, in patients with atypical clinical findings colicky abdominal pain may be the predominant symptom. In those cases, CT may be necessary to differentiate gastro-enterocolitis from alternative diagnoses. At CT, wall thickening with, usually, homogenous enhancement, inflammation of the peri-colic fat, ascites, and multiple air-fluid levels, may be present. Although these findings are non-specific, the portion of colon affected may suggest the presence of a specific organism [36].

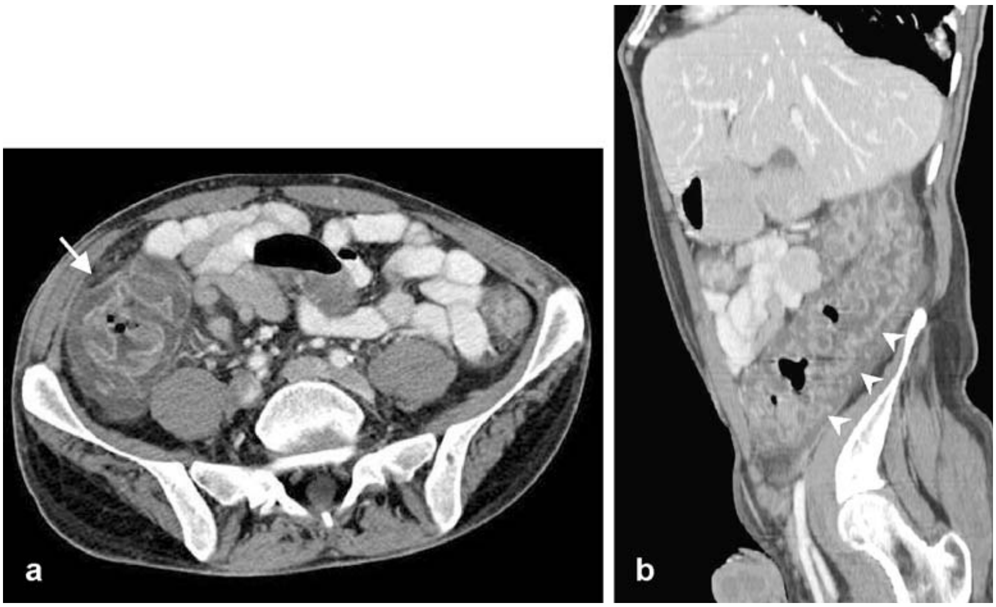

Fig. 6 Pseudomembranous colitis in a 44-year-old man on antibiotics because of meningitis and with acute abdominal pain in the lower abdomen. **a** MDCT scan performed with orally and intravenously administered contrast agent in the portal venous phase demonstrates colonic wall thickening up to 3 cm, low attenuation of bowel wall, and enhancement of luminal surface corresponding to diffuse colonic oedema with mucosal hyperaemia (*arrow*). **b** Sagittal image reveals the ascending colon and right flexure with alternating bands of higher and lower attenuation, an appearance called the accordion sign (*arrowheads*). Because the patient had a history of oral antibiotics use, these CT findings, although not specific, are highly suggestive of *Clostridium difficile*-related colitis

In patients on potent oral antibiotics, the normal bacterial flora of the colon is disrupted, resulting in the overgrowth of *Clostridium difficile* and causing pseudomembranous colitis. Although non-specific, CT findings include mural thickening, with a halo or target pattern caused by submucosal oedema, peri-colic inflammatory changes, and ascites [37, 38] (Fig. 6). The extent of bowel wall thickening in pseudomembranous colitis is usually greater than in other inflammatory or infectious bowel disease except Crohn's disease [39]. As a differentiating point, wall thickening in pseudomembranous colitis is often more irregular than in Crohn's disease [36]. Since pseudomembranous colitis predominantly affects the mucosa and submucosa, peri-colic stranding is often disproportionately mild relative to the colonic wall thickening [36]. Sometimes, contrast material is caught between thickened haustra, producing an accordion-like appearance [37], which is suggestive of pseudomembranous colitis but typically only occurs in severe cases [36].

Inflammatory bowel disease

The vast majority of patients with chronic IBDs such as ulcerative colitis or Crohn's disease experience chronic symptoms; however, in some patients, acute exacerbation or complications may lead to acute abdominal pain. The diagnostic value of CT is based on the excellent visualisation and documentation of extent and severity of bowel wall inflammation and the estimation of inflammatory activity of the disease. Although there is considerable overlap in the CT findings of ulcerative colitis and Crohn's disease, the location of the involved segment and the extent and appearance of wall thickening may help to distinguish the two. Extensive involvement of the right colon and small intestine is more common in Crohn's disease, whereas ulcerative colitis is typically left-sided. Bowel wall thickening in ulcerative colitis is usually diffuse and symmetric, while wall thickening in Crohn's disease may be eccentric and segmental with skip regions and may result in pseudodiverticula. In addition, the mean wall thickness in Crohn's disease is typically greater than in ulcerative colitis [36]. Proliferation of mesenteric fat and mesenteric lymphadenopathy suggests Crohn's disease rather than ulcerative colitis. On the other hand, the target sign, which represents a low-attenuation ring in the bowel wall due to deposition of submucosal fat, is seen more commonly in ulcerative colitis than in Crohn's disease [36]. The use of MPR significantly improves observer confidence in image interpretation, even if additional abnormalities are not revealed [40]. Because CT is able to demonstrate not only the bowel wall but also the surrounding tissue and adjacent structures, CT plays a major role in diagnosing extra-intestinal complications and is the standard technique for guided abscess drainage if ultrasound-guided drainage is not possible [36].

Bowel obstruction

Bowel obstruction is a common condition, with the diagnosis based on clinical signs, patient history, and radiographic findings. In order to ensure appropriate treatment, one must determine the site and cause of obstruction and the presence or absence of strangulation. The most common causes of small bowel obstruction (SBO) are adhesions because of prior surgery (Fig. 7), Crohn's disease, and tumours [41]. Intussusception is another relatively common cause of SBO in children but is much less frequent in adults [42] (Fig. 8).

In large bowel obstruction, the three main causes are carcinoma, diverticulitis, and volvulus [43].

Plain radiographs have long been used for confirmation of suspected bowel obstruction. Because of the diagnostic limitations of plain films, CT is increasingly used to identify the site, severity, and underlying cause of obstruction and to determine the presence of complications [44]. CT has an accuracy of up to 96% in cases of high-grade obstruction [45], while it is less accurate for low-grade SBO [46].

Fig. 7 Adhesive small bowel obstruction in a 43-year-old woman with diffuse acute abdominal pain and a history of kidney transplantation 1 year previously and surgery for anal carcinoma 6 weeks previously. Plain radiography did not provide sufficient information, so a MDCT examination was done and showed distended small bowel loops, measuring more than 2.5 cm in diameter, and collapsed small bowel loops. Coronal reconstructed MDCT clearly detects the transition zone (*arrow*) between distended proximal and collapsed distal bowel loops. Because there is no mass lesion at the transition zone, the diagnosis is adhesive small bowel obstruction. Open abdominal surgery revealed a fibrous adhesion between small bowel loops, confirming the diagnosis

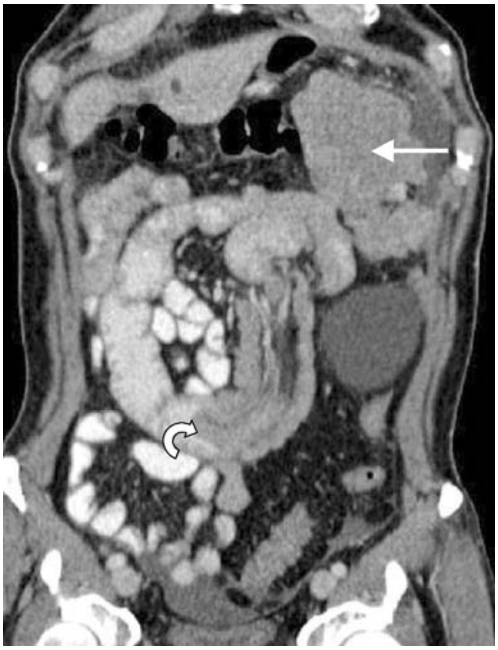

Fig. 8 Small bowel intussusception in a 54-year-old man with metastasising malignant melanoma and diffuse acute abdominal pain. Coronal reconstructed MDCT demonstrates a small bowel intussusception with mesenteric fat and vessels in the bowel lumen, resulting in a bowel-within-bowel appearance. The lead point is a jejunal melanoma metastasis (*curved arrow*). Note the additional sub-diaphragmatic metastasis (*arrow*)

The CT hallmark is demonstration of a definable transition from distended to decompressed bowel. Signs of malignant obstruction include mass, lymphadenopathy or abrupt transition with irregular bowel wall thickening [47]. In the absence of a mass or other abnormality in the area of obstruction, adhesions constitute the diagnosis of exclusion in the majority of patients [47]. Excellent contrast dynamics and the use of three-dimensional reconstructions render MDCT superior to conventional CT in patients with bowel obstruction. Especially, the determination of the transition point from dilated to non-dilated bowel can be difficult on axial slices alone [48–51]. Post-processing may enhance detection of the site of obstruction, diagnosis of adhesions, and analysis of the relationship between normal and abnormal bowel wall [52].

CT is also very helpful in differentiating between simple and closed-loop bowel obstruction [53]. Closed-loop obstruction, often secondary to adhesion or hernia, is characterised by mechanical bowel obstruction in which two points along the course of the bowel are obstructed at a single site. Characteristic CT findings are a C-shaped, U-shaped, or “coffee-bean” configuration of the bowel loop. Other findings suggestive of strangulation include fluid in the mesenteric leaves radiating out from the point of strangulation and the “whirlpool sign”, caused by the twisting of the bowel, with local engorgement of mesenteric vessels, mesenteric oedema, and bowel thickening [54]. In addition, because of its superior anatomical detail, MDCT may potentially detect subtle signs of strangulation, such as mesenteric stranding, poor bowel wall enhancement, wall thickening, and free air or fluid [55].

In the differentiation of mechanical obstruction from paralytic ileus, CT has been reported to be highly accurate [46]. Paralytic ileus is due to paralysis of the gut musculature and is a common problem in the postoperative period or may be secondary to ischaemic conditions, inflammatory or infectious disease, abnormal metabolic drug or hormone levels, or innervation defects [1]. CT can demonstrate involved bowel segments and may be helpful in determining the underlying cause [46, 52].

Ischaemic bowel disease

Ischaemic bowel disease shows a broad spectrum of clinical and radiological manifestations, ranging from transient ischaemia to necrosis of large portions of the bowel. Common causes of acute mesenteric ischaemia are embolic arterial occlusion, usually of cardiac origin, non-occlusive ischaemia, and, less frequently, superior mesenteric vein thrombosis, vasculitis, or dissection of the superior mesenteric artery [56]. In previous studies, CT has been shown to be very useful for the diagnosis of bowel ischaemia [56, 57]. Typical CT findings of bowel ischaemia—although non-specific—include bowel dilatation and wall thickening, abnormal bowel wall enhancement, intestinal pneumatosis, and ascites [58]. By evaluating the mesenteric vasculature, CT may sometimes be able to detect the underlying cause, such as atherosclerotic plaques, thrombus or occlusion (Fig. 9). MDCT facilitates the investigation of a true arterial phase of enhancement before opacification of adjacent veins [59], and thin-collimated reformations for better depiction of small vessels are recommended. We routinely perform dual-phase imaging to allow us to evaluate both arterial and venous patency as well as to define the pattern of bowel wall and parenchyma enhancement. Evaluation of axial images and multiplanar display are usually sufficient for detecting alterations of the bowel wall and the main mesenteric vessels, while VR images have the advantage of demonstrating mesenteric vessels, from their origin to distal branches, on a single projection [9].

Non-occlusive mesenteric ischaemia (NOMI) is commonly caused by decreased cardiac output, resulting in splanchnic hypoperfusion. Typical angiographic signs, including narrowing and vasoconstriction of multiple branches of the superior mesenteric artery, alternate dilatation and narrowing of intestinal branches, spasms of mesenteric arcades, impaired filling or occlusion of intramural vessels, reflux of contrast agent into the abdominal aorta,

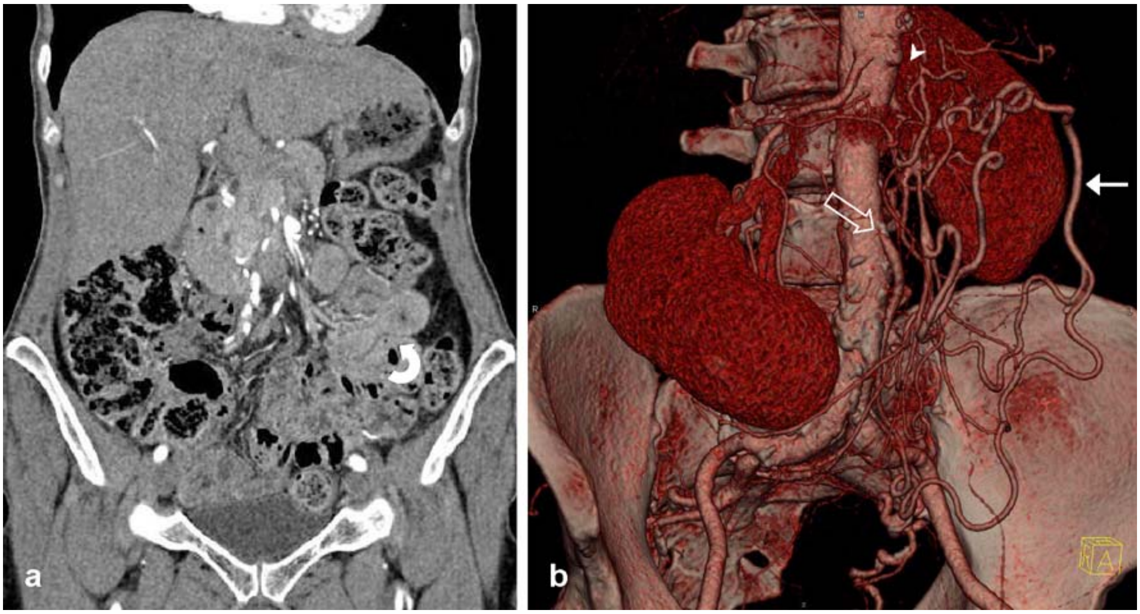

Fig. 9 Ischaemic bowel disease secondary to generalised arteriosclerosis in a 64-year-old woman with severe diffuse abdominal pain. **a** Coronal MDCT reconstruction shows thickening and heterogeneous enhancement of several small bowel loops (*curved arrow*). **b** Volume-rendered image delineates an occlusion of the superior mesenteric artery (*arrowhead*) and a high-grade stenosis of the inferior mesenteric artery (*open arrow*). Note the collateralisation through the dilated arc of Riolan (*arrow*)

and spread-out segmental arteries due to distension of bowel loops [60], are sometimes difficult to depict on CT angiography. Typical CT findings of bowel ischaemia in the setting of normally perfused mesenteric vessels then may facilitate the diagnosis of NOMI.

Gastrointestinal tract perforation

Gastrointestinal tract perforation may be found complicating appendicitis, diverticulitis, peptic ulcer disease, or following endoscopic procedures, particularly endoscopic biopsy or polypectomy [61]. CT is the most reliable diagnostic method to assess gastrointestinal perforation, as it allows detection of even small amounts of free air in the abdomen as a sign of perforation [62]. Viewing on a "lung window" setting may enhance the sensitivity of detecting subtle extra-luminal gas. Although evaluation could be made on non-enhanced CT examination, oral and intravenous administration of contrast is recommended for localisation of the site of perforation and for diagnosing the underlying cause. The localisation of extra-luminal air varies, depending on the position of the patient, and is usually not identical with the site of perforation. Helpful CT signs for localisation may be focal fluid, extravasation of orally administered contrast material, and local inflammatory changes.

Flank or epigastric pain

Ureteral stones

Urolithiasis is the most frequent cause of acute flank pain, but it rarely results in acute abdomen, referring to the classical definition [1]. Helical CT has been found to be more sensitive than excretory urography to plan treatment of patients with flank pain caused by obstructing ureteral stones [63]. Unenhanced, low-dose, MDCT provides a rapid and accurate diagnosis of ureteral stones, because almost all calculi are radio-opaque at CT [64]. Obstructing ureteral calculi are typically located at the ureteropelvic or ureterovesical junction. Subtle calculi may be detectable by the presence of focal peri-ureteral stranding. Secondary CT signs of urolithiasis include hydro-ureter, hydronephrosis, peri-nephric stranding, and renal enlargement. The use of oblique–coronal reconstructions is more effective for precise stone localisation and measurement than axial slices [65]. With MDCT, high-resolution, cine-viewing reconstructions can be obtained from thin-collimation acquisitions. The use of curved reformations provides unequivocal images focused on the ureteral stone.

When no stone is detected on non-enhanced CT, oral, intravenous, or rectal administration of contrast material may be required for alternative diagnoses. Non-calculous urinary tract abnormalities causing symptoms of urinary colic include acute pyelonephritis and renal cell carcinoma.

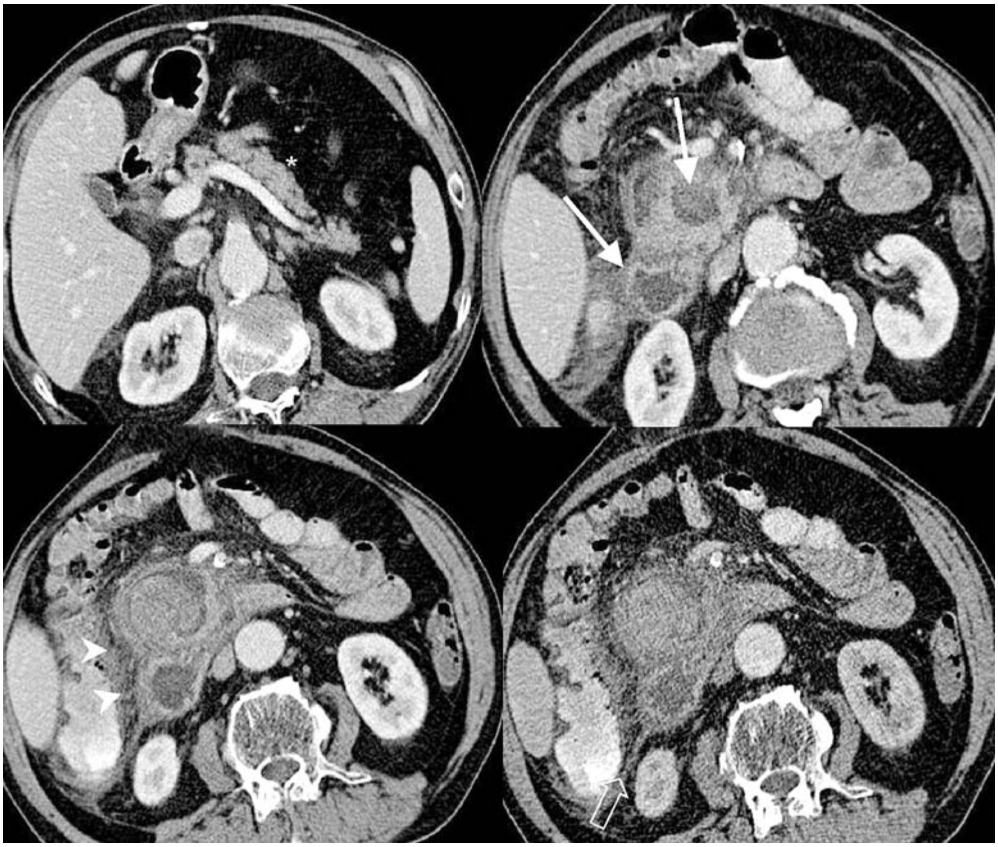

Fig. 10 Acute necrotising pancreatitis in a 69-year-old man with severe acute epigastric pain. Serial MDCT images show an enlarged pancreas and large, sharply demarcated, areas within the pancreatic parenchyma lacking enhancement (*arrows*). Note the small fluid collections in the anterior pararenal space (*arrowheads*) and the thickening of Gerota's fascia (*open arrow*). These CT findings are indicative of acute necrotising pancreatitis of the head and body of the pancreas. The tail is almost unaffected (*asterisk*)

Acute pancreatitis

In acute pancreatitis, CT findings correlate well with the severity of disease [66, 67]. Consequently, CT is the imaging modality of choice to classify pancreatitis and to detect complications such as pseudoaneurysms, porto-mesenteric venous occlusion, pseudocysts, or abscess (Fig. 10).

In mild forms, CT shows a peri-pancreatic inflammatory exudate and an otherwise normal appearing or homogeneously enlarged gland. In up to 28% of patients with mild pancreatitis, the results of CT examination may be normal [67]. In severe forms, small intrapancreatic fluid collections are present as a result of intraglandular necrosis. Necrotising pancreatitis exhibits necrotic regions as unenhanced areas sharply demarcated from normally enhancing parenchyma. Peri-pancreatic exudates may penetrate along fascial planes and extend to adjacent organs. Fluid collections typically accumulate in the anterior pararenal space, lesser sac, mesenteric root, and transverse mesocolon. The thinner collimation of MDCT reveals vascular complications such as pseudoaneurysms or thrombosis of the splenic and portal veins. Because of the rapid image acquisition time with MDCT, vascular contrast phases can be clearly separated [59, 68]. Arterial phase imaging allows direct visualisation of arterial branches without opacification of adjacent veins. Portal venous phase imaging facilitates evaluation of pancreatitis and associated complications such as venous thrombosis [59]. Curved planar reformations are useful in displaying the whole tortuous pancreas, tracing the cholangiopancreatic duct and peri-pancreatic vessels and highlighting the relationship of lesions with surrounding anatomical structures [69].

Conclusions

CT is a rapid, first-line, imaging modality with high accuracy in the diagnostic work-up of patients presenting with acute abdominal pain. Because of the wide spectrum of diseases leading to acute abdominal pain, one major advantage of CT is its ability to suggest alternative diagnoses if the suspected clinical diagnosis is unconfirmed. With the introduction of MDCT, the transformation from an axial cross-sectional imaging modality into a true three-dimensional one allows the viewer to display the study in any desired straight or curved plane or to approach the study from any desired vantage point using VRT. Undoubtedly, the role of MDCT in the investigation of acute abdominal disorders will further increase.

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